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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL MEMORANDUM 1361

CONCERNING THE FLOW ON RING-SHAPED COWLINGS

Part XIII

THE INFLUENCE OF A PROJECTING HUB

By D. Küchemann

Translation of "ZWB Untersuchungen und Mitteilungen Nr. 3144."

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Part XIII

THE INFLUENCE OF A PROJECTING HUB*

By D. Küchemann

Abstract: The influence of thickness and length of a hub projecting from an inlet opening was investigated on one of the two new classes of circular cowls reported in NACA TM 1360.

Outline:

I. STATEMENT OF THE PROBLEM

In some applications, there arises the problem of scooping a given air quantity out of the free stream, as, for example, through a circular opening in the case of an annular radiator. It could also be visualized, however, that such an encircling inlet opening might be provided in the installation of special propulsion units, for instance in the fuselage. One may regard such an annular inlet as an inlet with projecting hub for which the flow phenomena to be expected are already known to a great extent. One knows, moreover, from various model tests that, with such a projecting hub, one can reduce the excess velocities on the outside of the circular cowl but has to accept on the other hand a decreased total pressure in the entrance opening. (See for instance ref. 1.) More accurate data for evaluation of the usability of this inlet arrangement (from which the actual numerical amount of the separate phenomena in various arrangements could be estimated) are still lacking, however.

The properties of two new classes of circular cowls have been investigated in reference 2. We shall in the present report observe more closely the influence of the hub on one of these circular cowls. We select for this purpose the least contracted cowl of class IV with $F_E/F_a = 0.6$ and

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*"Ueber die Strömung an ringförmigen Verkleidungen. XIII. Mitteilung: Der Einfluss einer vorgezogenen Nabe." Untersuchungen und Mitteilungen Nr. 3144 (ZWB).

provide it with six different hub bodies which differ in thickness and length.[1] (Compare figs. 1 and 2.) The hubs obstructed 50, 65, and 80 percent of the entrance cross section F_E' of the circular cowl and were, beginning from the foremost point of the cowl, circular-cylindrical in its interior. For the short hubs, a nose in the form of a semiellipsoid of an axis ratio 1:2 was affixed so that the length l_N of the projecting part of the first hub was exactly equal to the diameter $2\ R_N$. In a second series, the hub was lengthened frontward by a cylindrical piece of the length of one diameter so that $l_N/2\ R_N$ became 2. The investigations are limited to pressure distribution and mass-flow measurements.

II. RESULTS

In the following figures, we indicated only the most significant results which show the important phenomena; the detailed measuring results may be had from the AVA.

From figures 3 and 4, one can see how the suction peaks at the outside of the cowl are lowered by the guiding action of the hub which shifts the stagnation point farther outward and reduces or eliminates separation (or welling-over) of the cowl boundary layer. For the case without hub the pressure distributions show the unfavorable properties of cowlings with slight rounding of the lip; the cowl lip appears, from the pressure distributions, to become increasingly rounded out with growing hub size. Accordingly, the excess velocities decrease sharply (figs. 5 and 6). The magnitude of this reduction depends on the inlet velocity ratio; it is highest when the entering flow is completely throttled and can, naturally, hardly be ascertained at all when free-stream velocity prevails in the entrance cross section. How far this drop in excess velocity increases the critical drag-break Mach number cannot be determined, since the character of the pressure distribution also is changed entirely by the hub. Furthermore, the reduction of the excess velocities is particularly noticeable in case of oblique approach flow due to the hub as can be seen from figures 7 and 8.

The decrease of the excess velocities may be explained partly on the basis of potential theory; we recall that thrust forces must act on the outside of the cowl (compare refs. 1 and 3) and that a certain area must be put at their disposal if the negative pressures are not to drop below certain values. If the hub projects very far from the fairing, it cannot be put to use for the application of the thrust forces so that only the frontal area of the cowl $F_a - F_E'$ could be considered as thrust area. As is discussed in detail in reference 1, a decisive factor for the

[1]As no symbol list was included in the German text, a list has been compiled by the NACA reviewer and is given in an appendix.

magnitude of the excess velocity is in addition to the inlet velocity ratio, v_E/v_o, the ratio between the entrance area and the thrust area, that is, the quantity $\left(F_E' - F_N\right)/\left(F_a - F_N\right)$, which replaces the contraction, F_E/F_a, in the hubless inlet. This quantity decreases more and more with increasing thickness of the hub, that is, the contraction of the cowl increases and the cowl becomes more favorable. The maximum excess velocity v_{max}/v_o which would be obtained for $v_E = 0$ if the cowl had a constant pressure distribution (Ruden's entrance cone of minimum contraction) is calculated from

$$\frac{v_{max}}{v_o} = \sqrt{\frac{1 - \frac{F_N}{F_E'}\frac{F_E'}{F_a}}{1 - \frac{F_E'}{F_a}}}$$

For the arrangements investigated we obtain the values:

Hub ratio F_N/F_E'	Contraction $\dfrac{1 - F_N/F_E'}{F_a/F_E' - F_N/F_E'}$	Excess velocity v_{max}/v_o for $v_E = 0$
0	0.60	1.58
.50	.43	1.33
.65	.34	1.24
.80	.23	1.14

These values of excess velocity are not attained with the cowl used since it is not a Ruden minimum form; for the long hub with a larger radius of curvature at the lip where the presuppositions probably come true, the minimum values are exceeded by approximately 10 percent.

There is a second reason, however, which is responsible for the reduction of the excess velocities: (that is) the flow separation at the hub. This phenomenon is, moreover, expressed in the fact that at the entrance the full total pressure is not attained. For two different flow quantities, the total pressure distributions at the entrance (beginning of the cylindrical part) for the various arrangements in rectilinear flow are shown in figure 9; figures 10 and 11 show the values averaged over the entrance cross section referred to the stagnation pressure of the approach flow which is designated as inlet efficiency η_E. One can see that the losses rise with increasing hub thickness and length and reach noticeable amounts in case of the thickest hub. The numerical values themselves, however, can give only a clue, since they are certainly caused, to a high extent, by the small model size (maximum outer diameter of the hub 200 mm, free-stream velocity about 40 m/s). It should further be pointed out that the inlet efficiencies depend also very considerably on the shape of the hub and are, for instance, essentially less favorable in forms which are thickened ahead of the inlet and are again contracted at the entrance. (Compare, for instance ref. 1.) In case of oblique approach flow, the separation phenomena become still less clear. In figure 12, one can see measurements for the most extreme arrangement in a vertical center section which shows the greatest variations. The entrance losses for static condition for the hub $F_N/F_E' = 0.5$ may be taken from reference 2. For the thicker hubs, the inflow for static conditions takes place practically without losses.

III. SUMMARY

In a circular cowl, the influence of a hub body projecting from the inlet opening was investigated; the reduction of excess velocities on the outside of the cowl and the amount of total pressure losses in the inlet as a function of thickness and length of the hub were ascertained by measurements. The tests are visualized for the application in annular radiators and the installation of special propulsion units; in the latter case, such an arrangement would have to show many constructive and other advantages in order to prevail over the customary forms of installation since one does not gain anything in frontal area and always has to accept noticeable entrance losses.

Translated by Mary L. Mahler
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APPENDIX

SYMBOLS[1]

$F_a = \pi R_a^2$

$F_E = \pi R_E^2 - \pi R_N^2$

F_E/F_a	contraction of cowl
$F_E'/F_a = R_E^2/R_a^2$	contraction of circular cowl without hub

$F_E' = \pi R_E^2$

$F_N = \pi R_N^2$

p	local static pressure
p_{ges}	local total pressure
p_o	static pressure in the undisturbed flow
$q_o = \rho V_o^2/2$	dynamic pressure of approach flow
R_a	maximum outer radius of cowl
R_E	radius of cowl in entrance cross section (narrowest cross section in the inlet part)
R_N	radius of hub in entrance cross section
v_E	mean value of velocity in the entrance cross section
v_E/v_o	inlet-velocity ratio
v_{E_o}/v_o	inlet-velocity ratio for $\alpha = 0^\circ$ for the same position of sliding throttle valve
v_{max}	maximum velocity on the outside of the circular cowl

[1]This appendix was added by the NACA reviewer.

v_o	undisturbed free-stream velocity
x, r	rectangular coordinates; x in direction of the axis of rotation
α	angle of attack
l_N	length of hub ahead of inlet
η_E	inlet efficiency; mean value of $\frac{p_{ges} - p_o}{q_o}$ over the entrance cross section

IV. REFERENCES

1. Küchemann, D., and Weber, J.: Das Einlaufproblem bei Triebwerks-verkleidungen. Mtt. d. Dt. Akad. d. Luftfahrtforschg, 1943.

2. Küchemann, D., and Weber, J.: Ueber die Strömung an ringförmigen Verkleidungen. XII. Mitteilung: Zwei neue Klassen von Ringhauben. UM 3111, 1944. (Available as NACA TM 1360.)

3. Küchemann, D., and Weber, J.: Zur Fraget Kreierunde oder ovale Hutzenl. UM 3058, 1944.

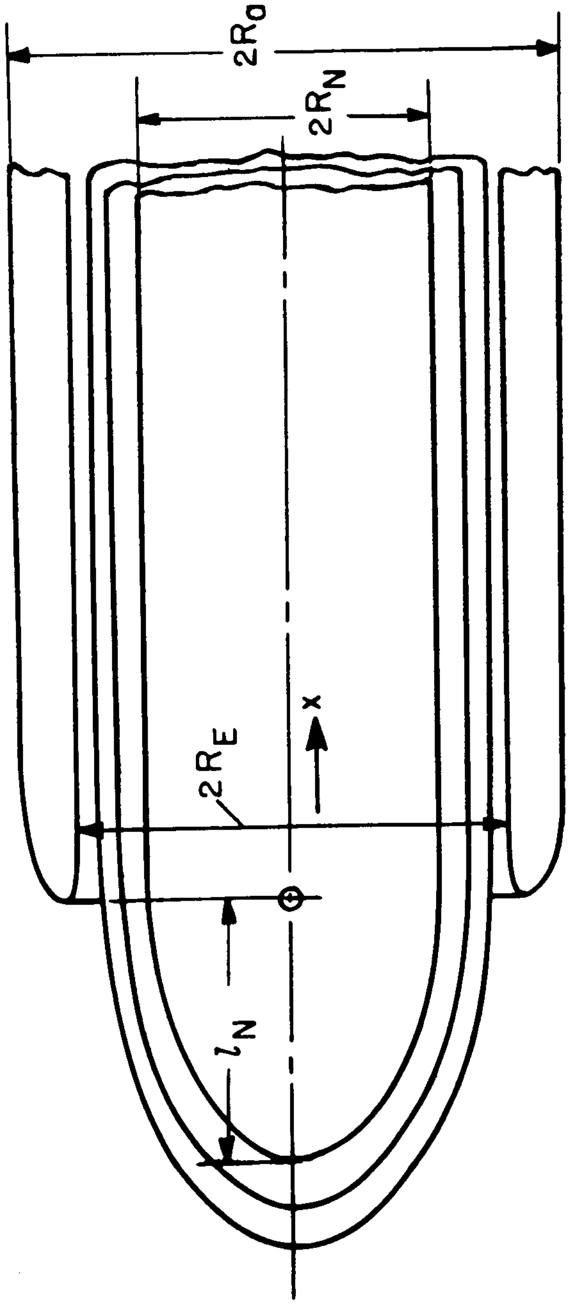

Figure 1.- Circular cowl AVA IV; $F_E'/F_a = (2R_E/2R_a)^2 = 0.6$ with short hubs $l_N/2R_N = 1$.

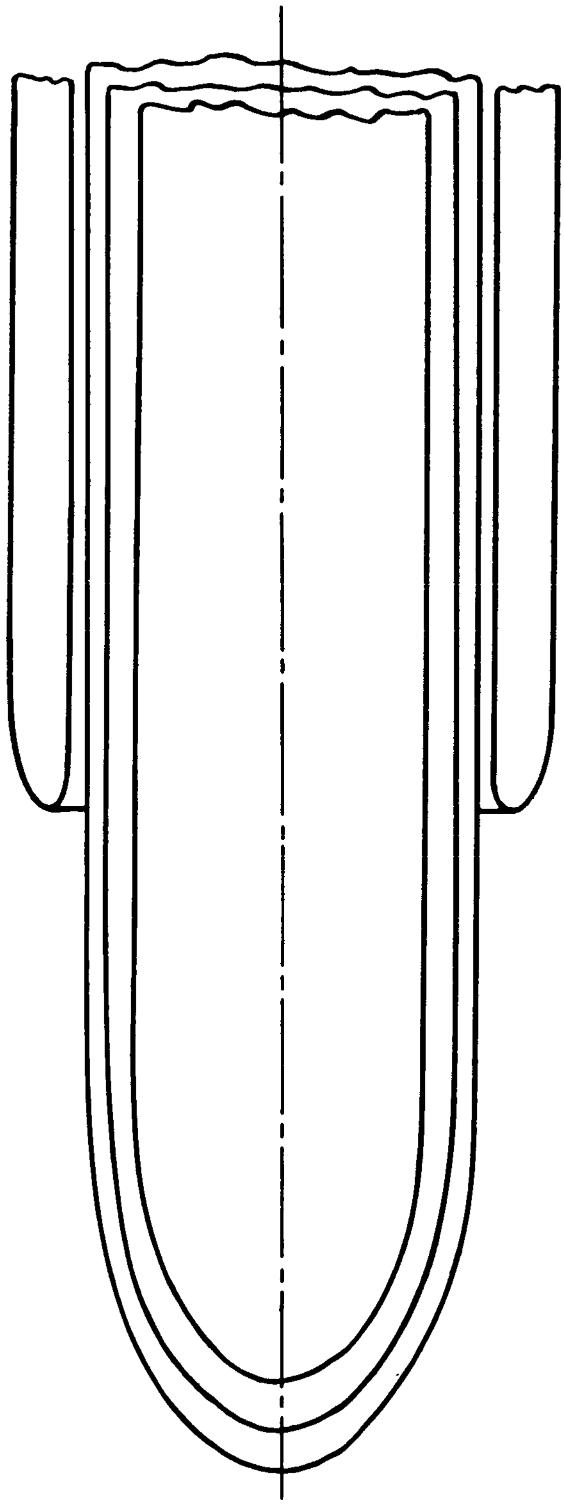

Figure 2.- Circular cowl AVA IV/0.6; with long hubs $l_N/2R_N = 2$.

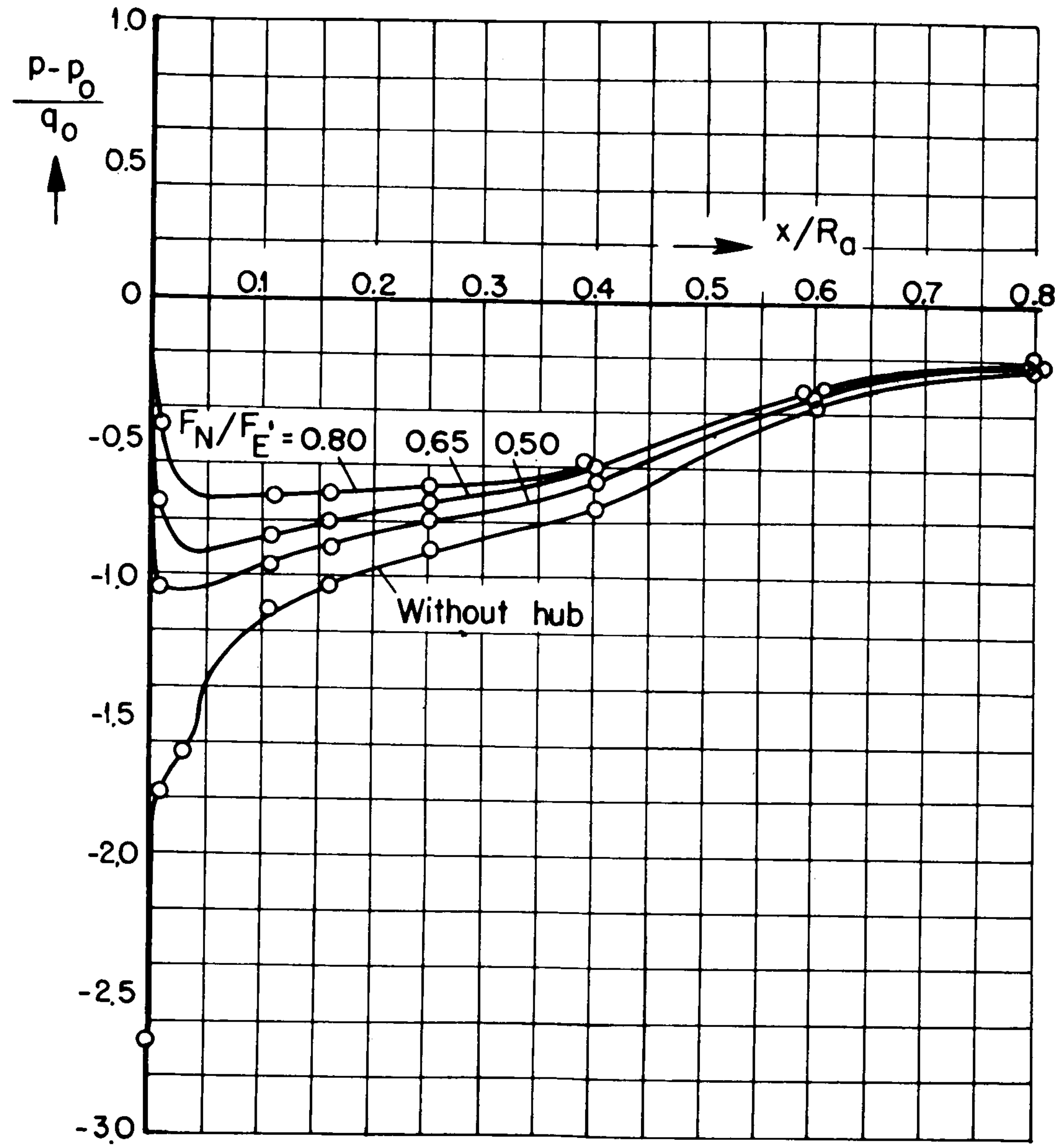

Figure 3.- Circular cowl IV/0.6; $\alpha = 0^{o}$; $v_E = 0$; with short hub $l_N/2R_N = 1$; pressure distribution outside.

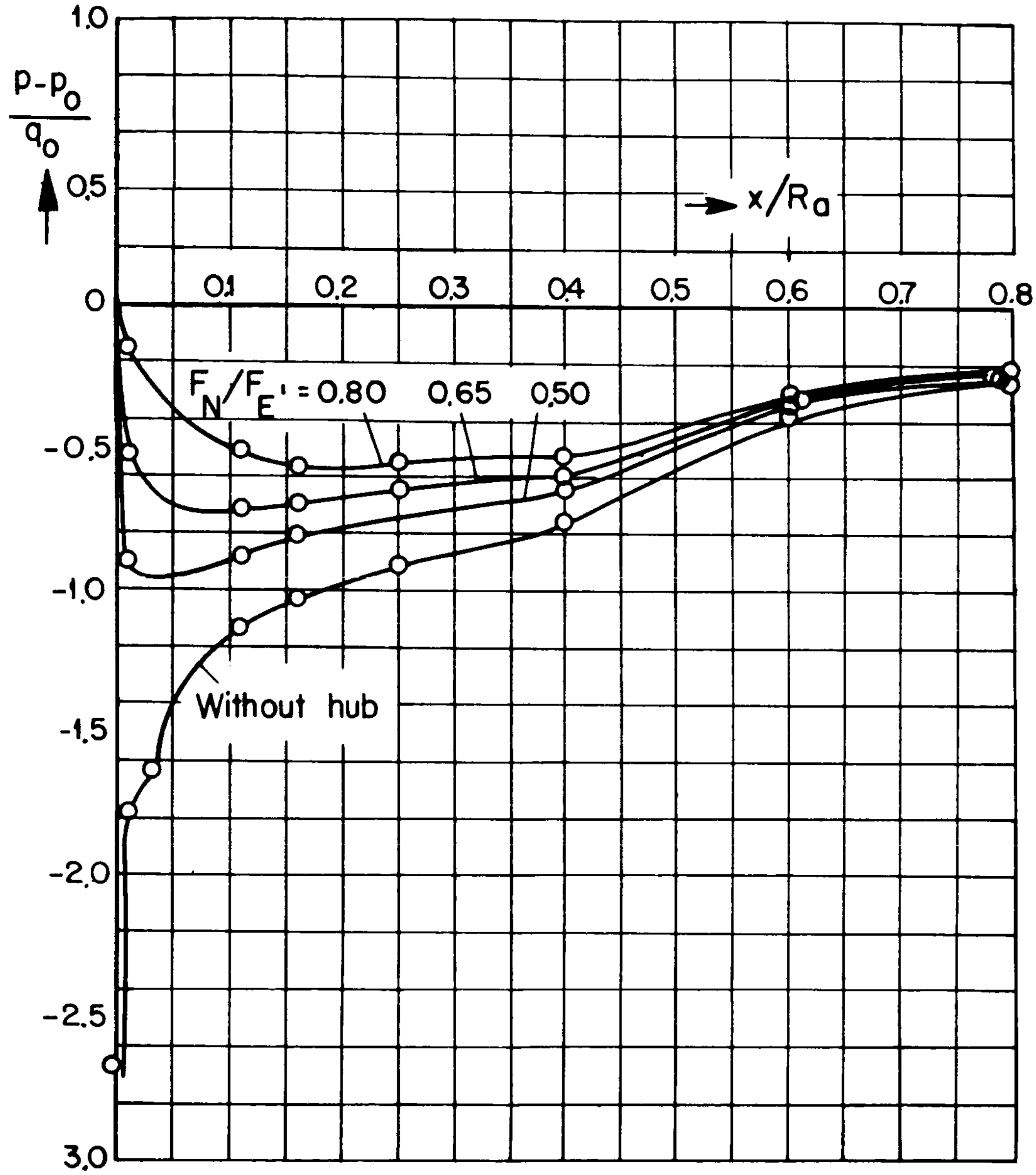

Figure 4.- Circular cowl IV/0.6; $\alpha = 0^{\circ}$; $v_E = 0$; with long hub $l_N/2R_N = 2$; pressure distribution outside.

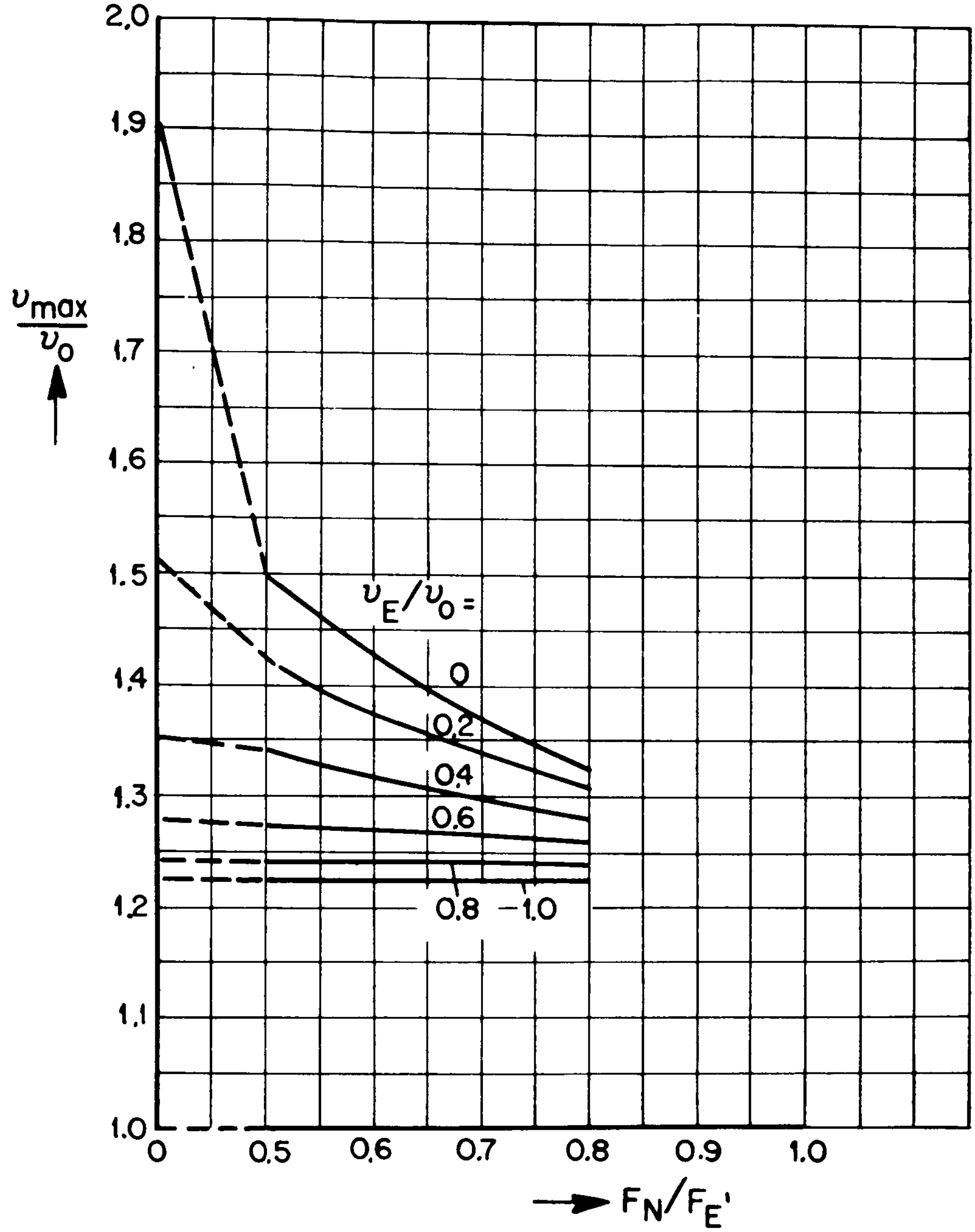

Figure 5.- Circular cowl IV/0.6; $\alpha = 0^o$; with short hub $l_N/2R_N = 1$; excess velocities outside.

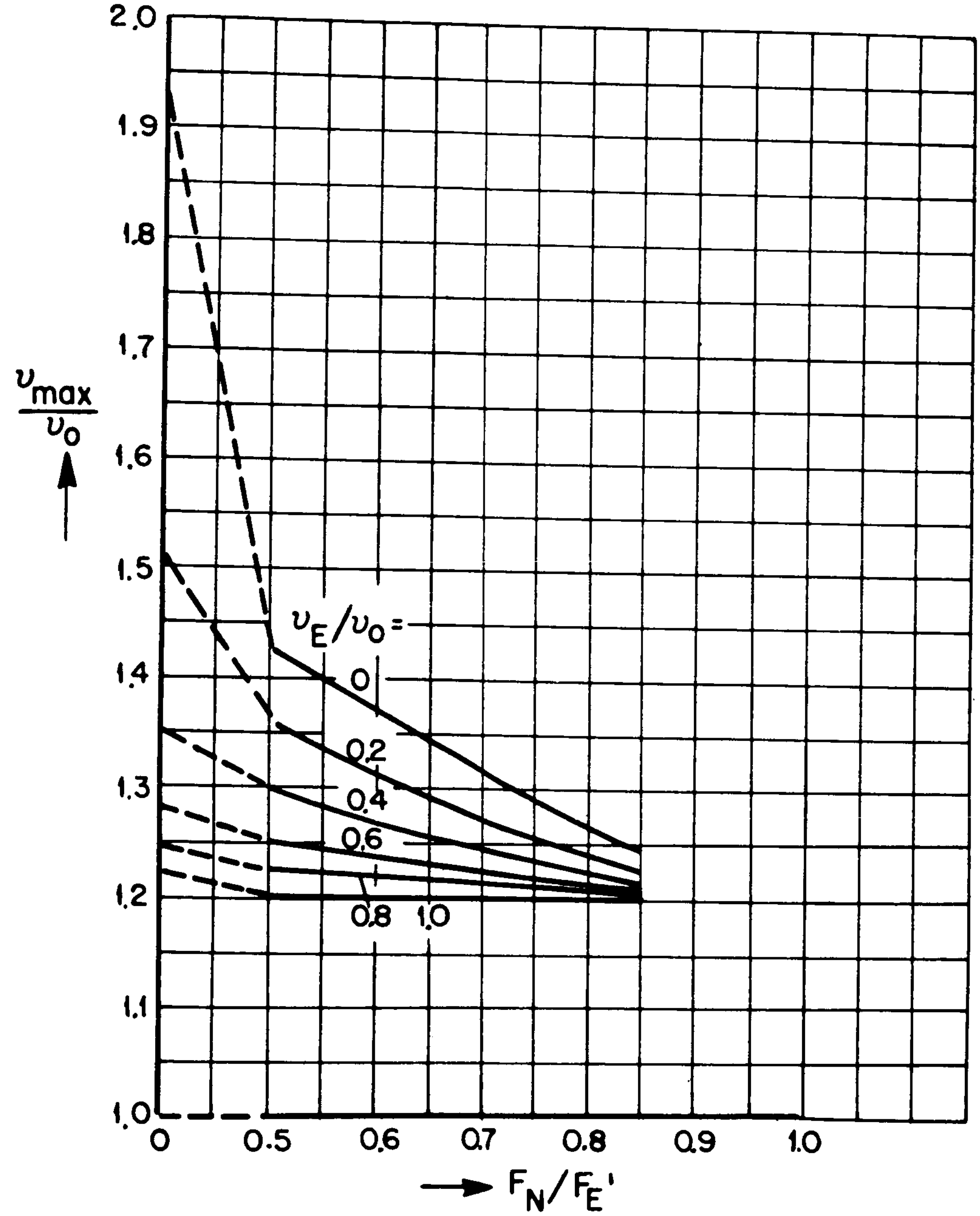

Figure 6.- Circular cowl IV/0.6; $\alpha = 0^o$; with long hub $l_N/2R_N = 2$; excess velocities outside.

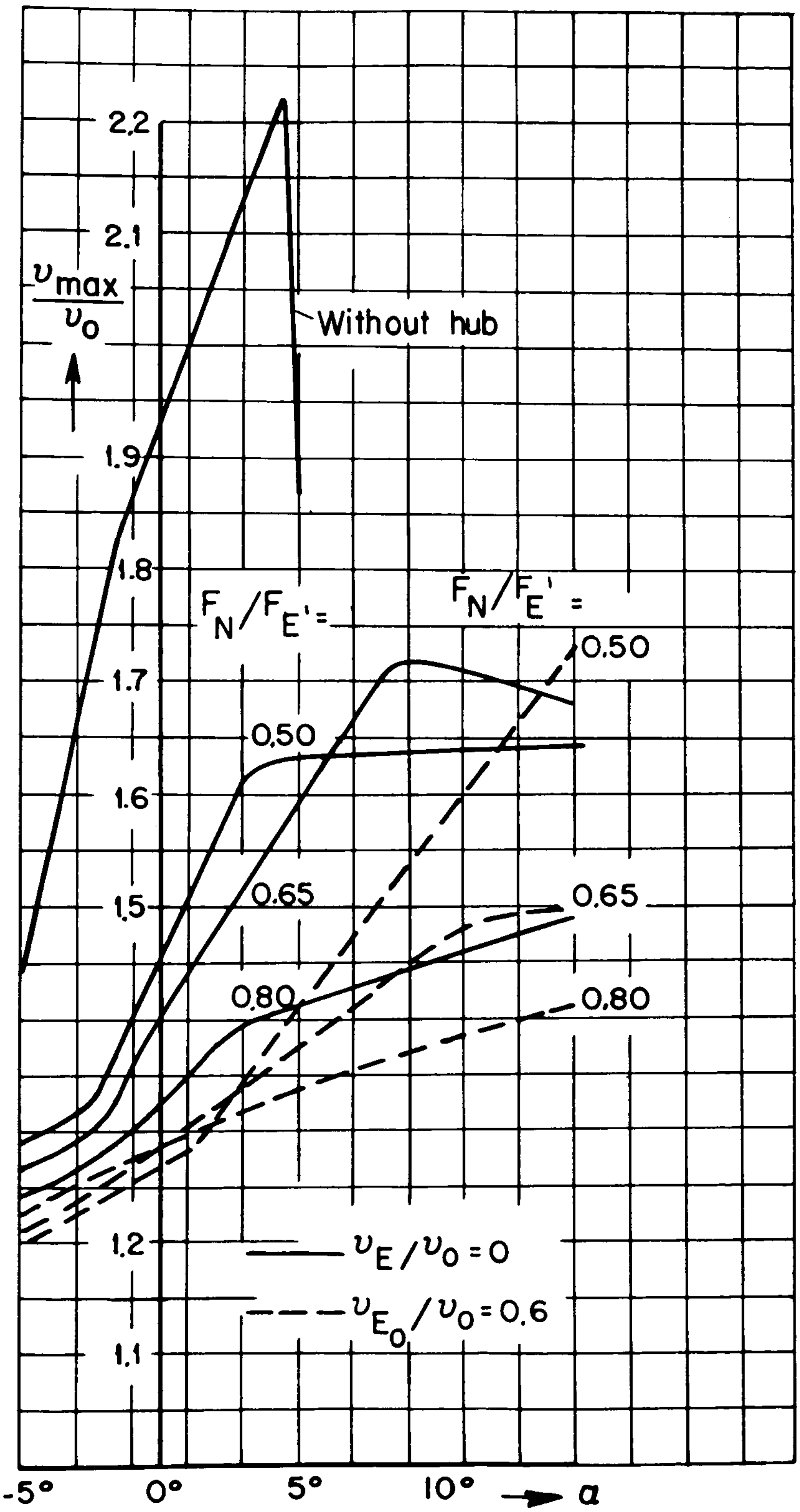

Figure 7.- Circular cowl IV/0.6; with short hub $l_N/2R_N = 1$; excess velocities outside.

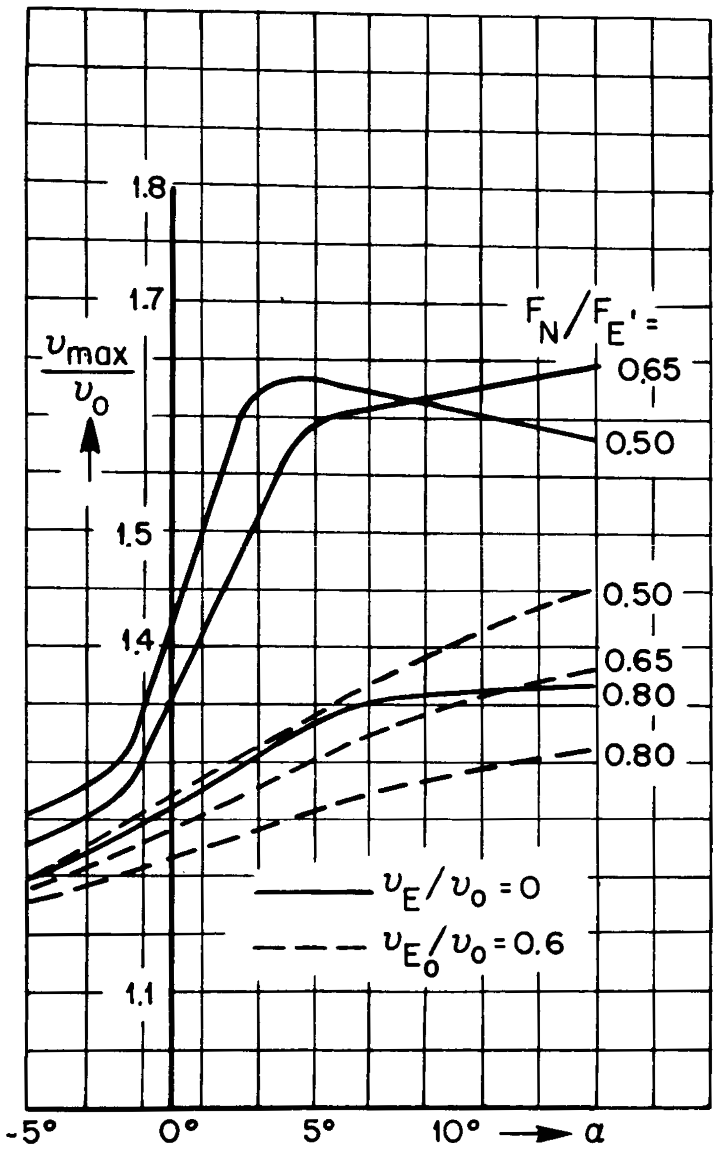

Figure 8.- Circular cowl IV/0.6; with long hub $l_N/2R_N = 2$; excess velocities outside.

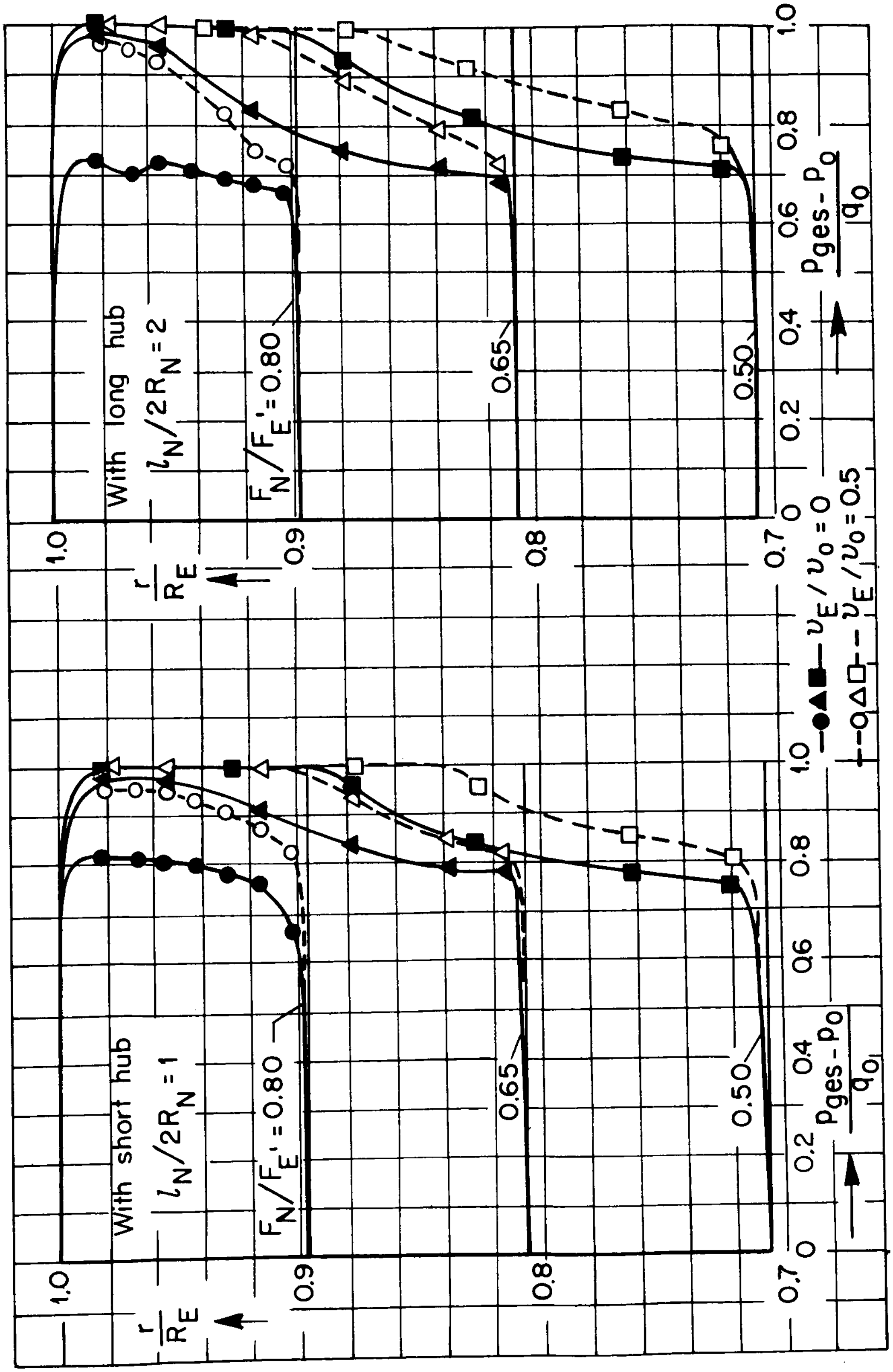

Figure 9.- Circular cowl IV/0.6; $\alpha = 0^{\circ}$.

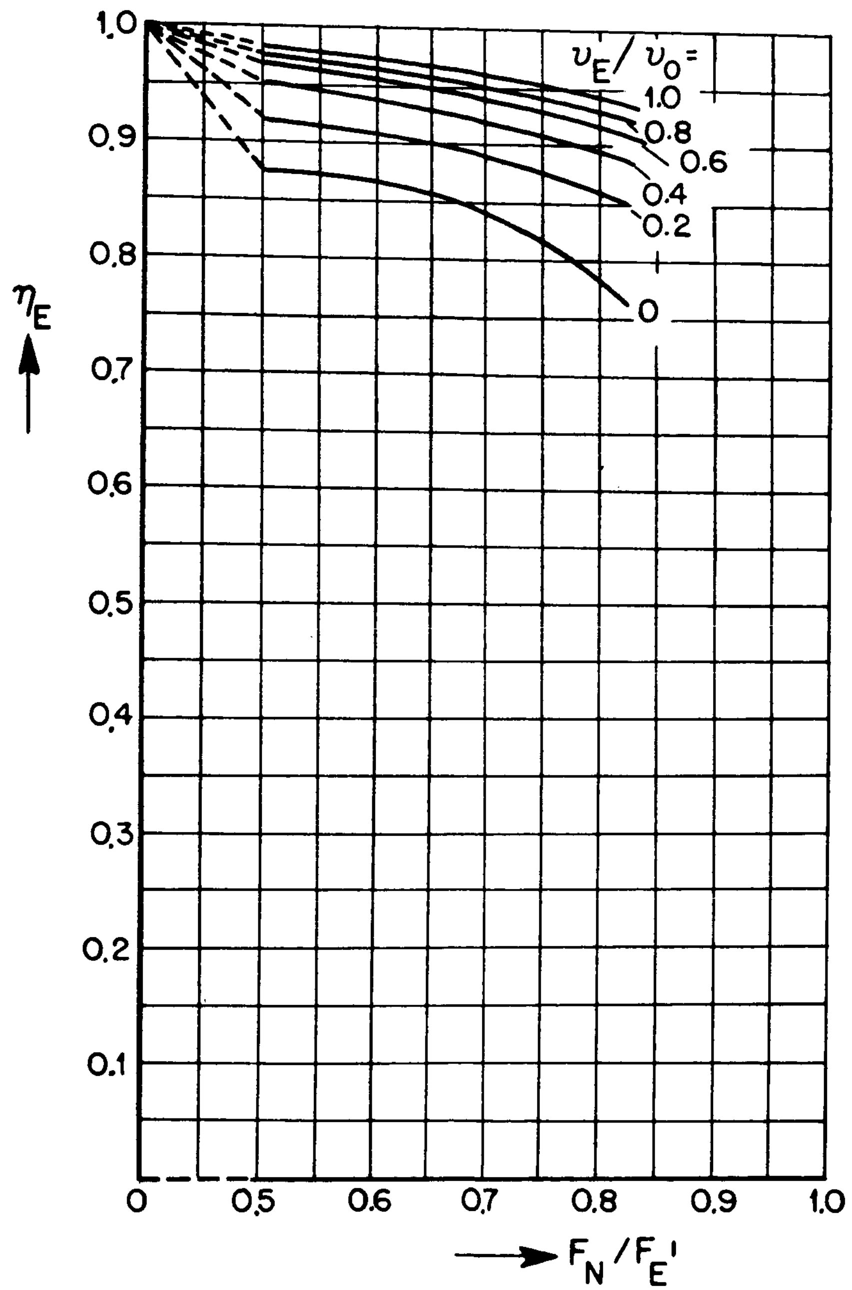

Figure 10.- Circular cowl IV/0.6; $\alpha = 0^o$; with short hub $l_N/2R_N = 1$; inlet efficiency.

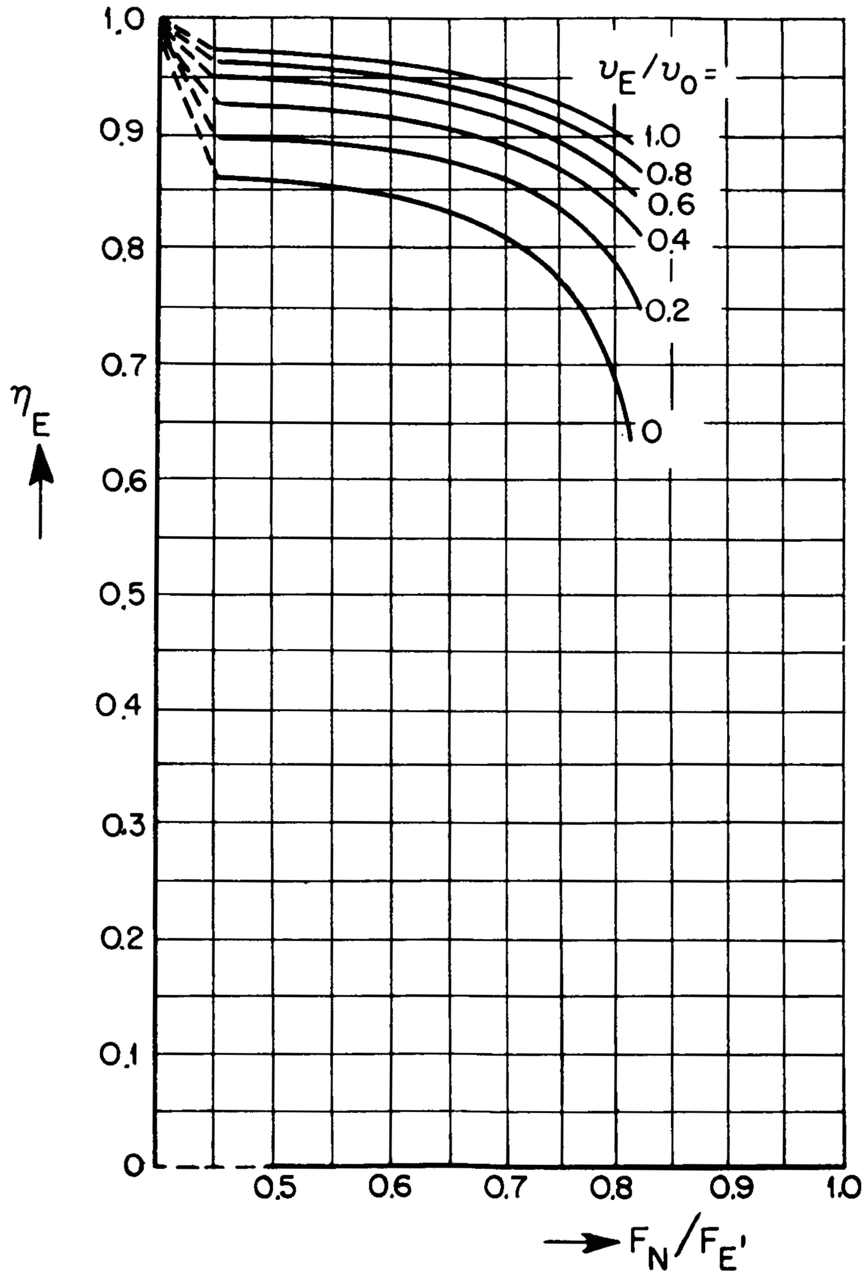

Figure 11.- Circular cowl IV/0.6; $\alpha = 0^{\circ}$; with long hub $l_N/2R_N = 2$; inlet efficiency.

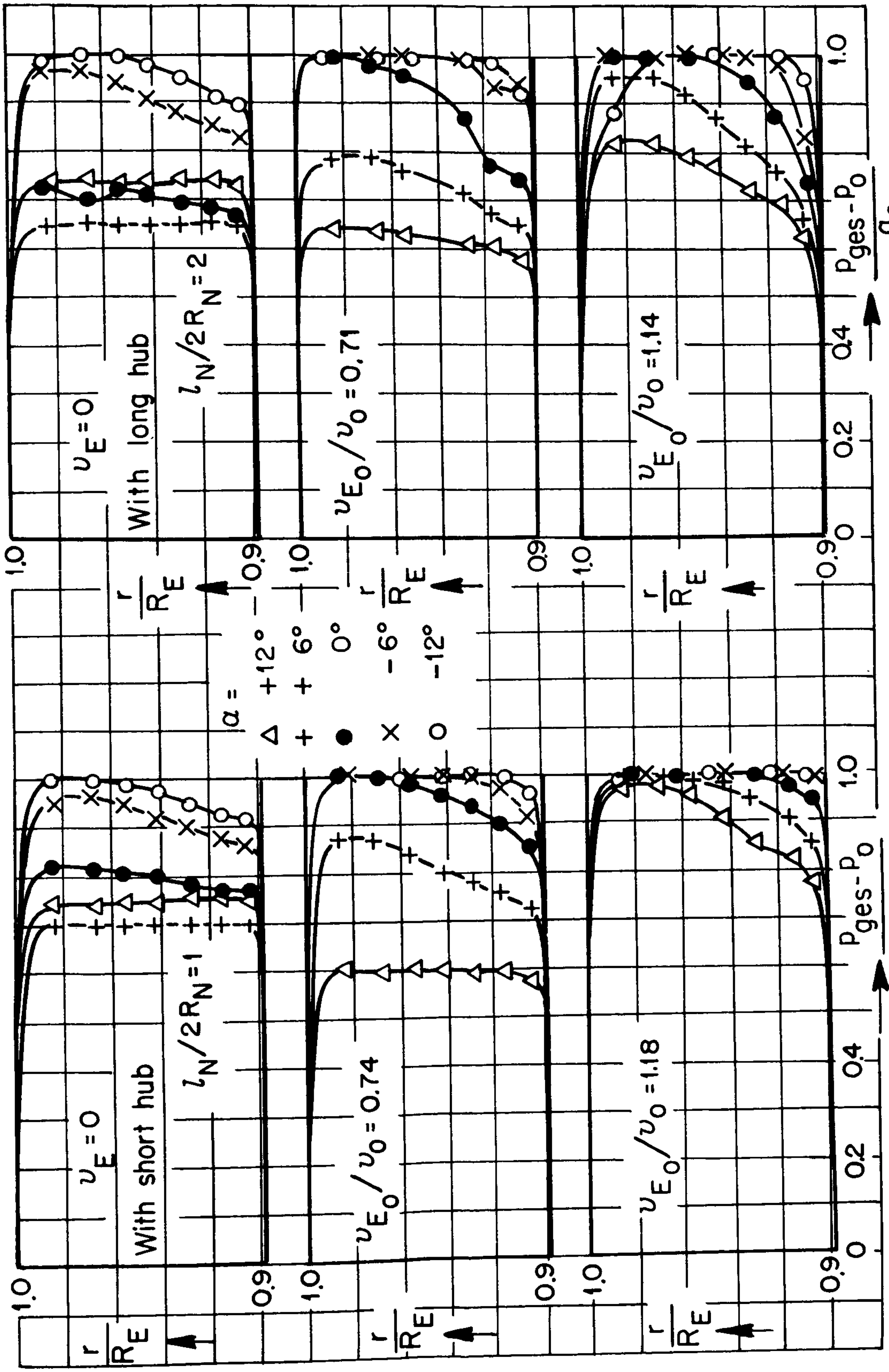

Figure 12.- Circular cowl IV/0.6; $F_N/F_E' = 0.8$.